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May 1973

PLASTIC CONSTRUCTION MATERIALS

PLASTIC PIPE FOR INTERIOR AND EXTERIOR COLD WATER DISTRIBUTION SYSTEMS

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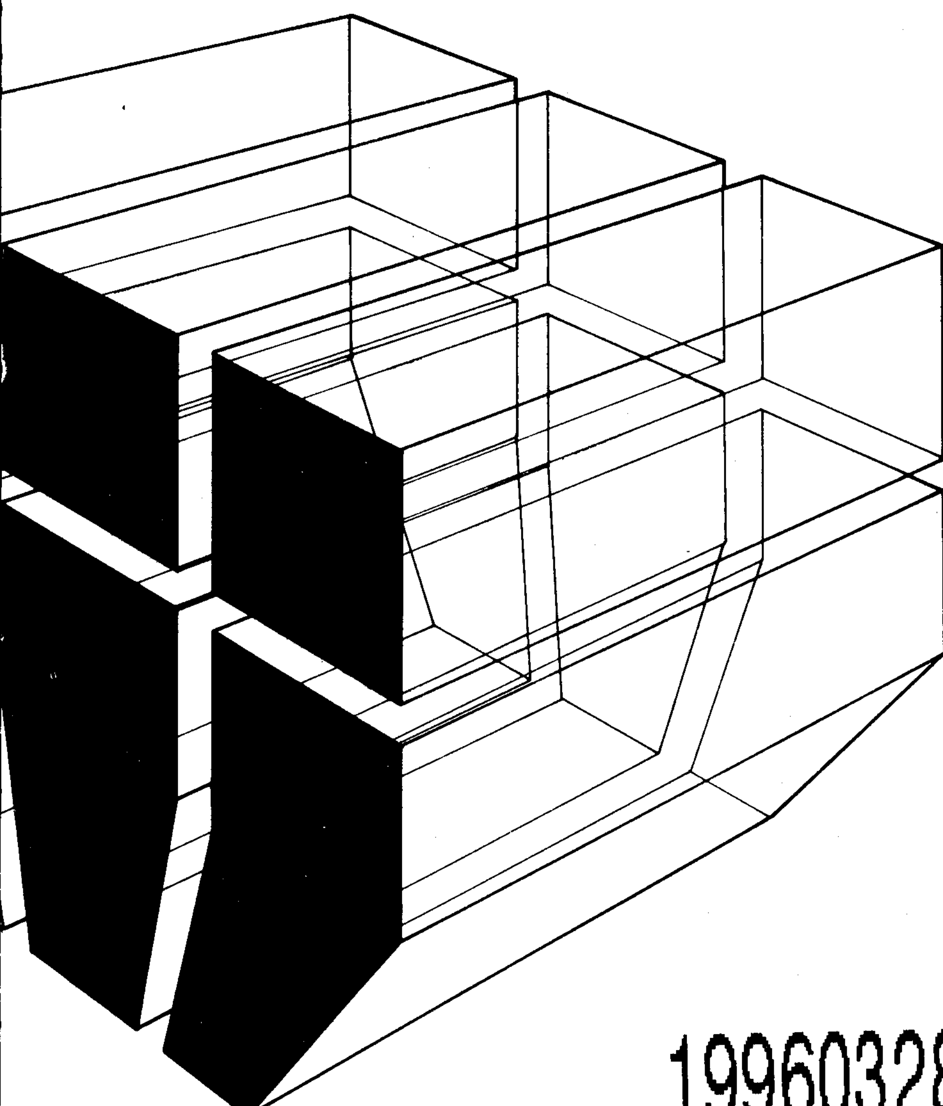
by
Walter J. Mikucki



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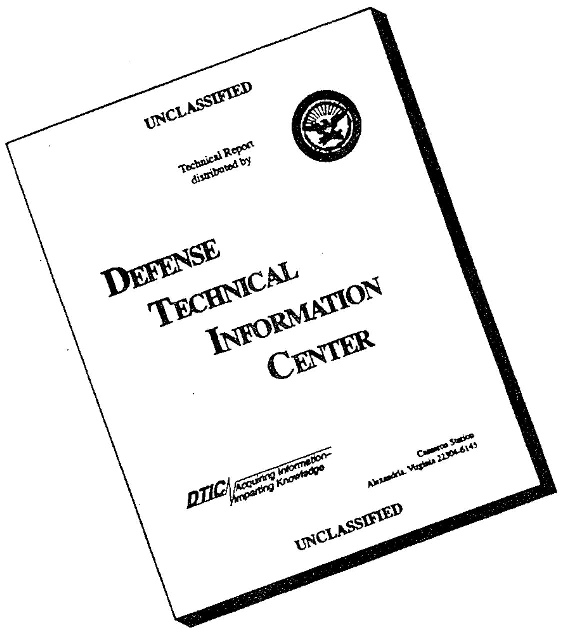

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TECHNICAL REPORT E-14

PLASTIC PIPE FOR INTERIOR AND EXTERIOR COLD WATER DISTRIBUTION SYSTEMS

(Plastic Construction Materials)

by

Walter J. Mikucki

May 1973

Department of the Army

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ABSTRACT

This report evaluates the suitability of unreinforced plastic piping for use in small diameter (less than or equal to 4 in.), interior and exterior potable cold water distribution systems. Special consideration was directed toward the storage, handling, fabrication and installation techniques peculiar to plastic pipe. Also included are guidelines for the design and installation of plastic piping systems. Three major resins were considered: acrylonitrile-butadiene-styrene (ABS), polyvinyl-chloride (PVC) and polyethylene (PE). Polyethylene pipe is suitable only for low pressure applications; PVC and ABS pipe meet the study criteria of being able to withstand a pressure of 150 lb/in.^{2} An appendix recommends additions to Corps of Engineers Guide Specification CE 501, Cold Water Distribution.

FOREWORD

This study was initiated at the Construction Engineering Laboratory (CEL)* of the Ohio River Division Laboratories at the request of the Directorate of Military Construction, Office, Chief of Engineers, and continued at the Construction Engineering Research Laboratory (CERL). The study was funded under Project OK1, "Engineering Criteria for Design and Construction," Task 02, "Materials Evaluation," Work Unit 004, "Plastic Construction Materials." Donald Knudsen was Technical Monitor.

The investigation was performed under the direction of Richard G. Donaghy, Chief of the Electromechanical and Environmental Systems Division, CERL. This report was prepared by Walter J. Mikucki. Col. R.W. Reisacher is Director of CERL and Dr. L.R. Shaffer is Deputy Director.

* In October 1968 CEL became the Construction Engineering Research Laboratory (CERL), located in Champaign, Illinois since July 1969.

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PLASTIC PIPE FOR INTERIOR AND EXTERIOR COLD WATER DISTRIBUTION SYSTEMS

1 INTRODUCTION

Purpose and Scope. This report is concerned with (a) evaluating the suitability of plastic piping for use for interior and exterior potable cold water distribution systems, 4 in. diameter and under, and (b) providing guidance for the design and installation of such plastic piping systems. Properties of the materials commonly used to manufacture plastic pipe, the standards to which the manufactured pipe must conform and the storage, fabrication and installation techniques required for the proper application of plastic pipe in military construction were examined.

The study performed considered only piping made of unreinforced plastic materials, and was restricted to consideration of the use of such piping in potable, cold water distribution service.

Background. Developments in the field of plastics have provided materials which are competitive, technically and economically, with materials now specified for many aspects of military facilities construction. In recent years plastic pipe has found increasing favor in civilian plumbing and water distribution applications. The characteristics of light weight, corrosion resistance and low cost make plastic pipe also desirable for military construction applications. The cost of handling, fabrication, and installation of plastic piping offers the potential for substantial reductions in piping system costs when compared to conventional piping materials. In addition, some of the materials now used in water distribution systems are, or will become, scarce and costly, making the lower materials cost of plastic piping attractive.

Previous and Current Use of Plastic Pipe. A search of historical records reveals that the application of plastics to piping systems dates back many years in both the United States and foreign countries. It is only since 1940, however, that the major developments which brought forth the current technology have occurred. The quality of the pipe materials and methods of fabrication have improved each year, and with such improvement has come increased user acceptance. Material and fabrication standards have been developed to guide the user in obtaining a satisfactory piping system.

Principal current applications of unreinforced plastic piping are water distribution, gas distribution, process piping, electrical conduit, and drain, waste, and vent systems within buildings. Such construction industry organizations as the Building Officials Conference of America, the International Association of Plumbing and Mechanical Officials and the Southern Building Codes Congress have recognized plastic pipe for cold water service and have formulated model building codes to allow and assure the proper use of plastic pipe in construction. Many other special applications have been found, and special compounding of the plastic material is possible to meet unique requirements.

General Standards and Specifications. Plastic materials may be categorized in two general classes: thermo plastics and thermosetting plastics. Thermoplastic material can be repeatedly softened by an increase in temperature and subsequently hardened by a decrease in temperature. In other words, it can be formed and reformed repeatedly by application and removal of heat. Thermosetting plastic is a material which can be changed into an infusible product when cured by the application of heat or a curing chemical. This means that it can be formed only once.

Current use of plastics in potable water systems is for the most part confined to thermoplastic materials, only three of which are commonly used: polyethylene (PE), acrylonitrile-butadiene-styrene (ABS), and polyvinyl-chloride (PVC). Other materials, such as polybutylene, cellulose acetate butyrate, and polypropylene have been used to a lesser extent.

General material specifications for the above materials as well as standards covering testing, fabrication, installation, and inspection have been developed for general use by the following organizations:

- National Bureau of Standards (NBS)
- American Society for Testing and Materials (ASTM)
- United States of America Standards Institute (ANSI)
- Plastic Pipe Institute (PPI)
- National Sanitation Foundation (NSF)

General Problem Areas. Plastics, like any material, have their limitations and must be used within such limitations. A review of problems cited in the literature as well as discussion with users has indicated that almost all problems in recent years have resulted from failure of the designer, installer, or user to recognize the chemical and physical limitations of the piping and joining materials.

In the early years of plastic piping usage, leakage and other types of failures occurred because of improper compounding of the plastic piping and joining materials, inadequate understanding of the reaction of the plastics with fluids being conveyed, and lack of knowledge of mechanical properties. The developments of current technology have eliminated these deficiencies, and the most common problems encountered today include:

Improper selection of materials or joining materials

Exposure of piping material to adverse environment during storage, installation, or operation

Evaporation of solvent by exposing cement to air

Exceeding mechanical strength of the pipe by application of axial or torsion loads to joints, overpressure, or inadequate clearance for thermal expansion and contraction

Physical damage during storage, handling, and installation

Improper joining methods and fittings

Poor workmanship during installation

Inadequate testing of completed system.

The foregoing problems reflect inadequacies of design, fabrication, installation, and operation, rather than deficiencies of plastic piping materials themselves.

Method of Investigation. The study reported here was conducted in the following steps:

1. Definition of the functional requirements to be met in terms of types of facilities to be served, operating characteristics (pressures, temperatures), operating environment (ambient temperatures, humidity, soil conditions, mechanical loads), and water quality maintenance.

2. Evaluation of available material characterstics and methods of fabricating, joining, and testing.

3. Comparison of available material characteristics with functional requirements and evaluation of the adequacy of materials and fabricating and joining methods.

4. Evaluation of user experience.

5. Definition of the limitations of plastic piping materials and fabrication, installation, and testing methods.

6. Preparation of draft guidance covering material selection and methods of fabrication, storage, handling, installation, and testing.

2 STUDY FINDINGS

Performance Requirements. The performance requirements for plastic piping and fittings are a reflection of the types of facilities being served. In this study, the following types of service were considered:

1. Service lines to buildings and facilities—the connection from the water distribution main to the building or facility being served.

2. Distribution of water within buildings or facilities, from the building or facility line to the point of water use—includes piping enclosed within wall spaces and exposed piping.

3. Underground irrigation piping, including connections to sprinkler heads.

Plastic piping in these types of service must perform in the following environment:

Pressure: maximum of 150 psig

Ambient Temperature: 0° to 130°F

Fluid Temperature: 35° to 90°F

Ambient Moisture: 0–100%

In addition, corrosive environments may be generated, either in the air or the ground, where organic compounds are present along with moisture. Vibration and the possibility of mechanical impact are also considerations.

Material Characteristics. The following is a general description of polyethylene, acrylonitrile-butadiene-styrene, and polyvinyl-chloride piping and fitting materials. Pipe certified for potable water use will bear the symbol of the certifying agency (e.g., National Sanitation Foundation).

Polyethylene (PE). While polythylene has many applications, this discussion will be confined to its use for piping cold potable water. Polyethylene pipe is pro-

duced in accordance with the requirements of the National Bureau of Standards, U.S. Department of Commerce, Product Standards PS 10-69, PS 11-69, and PS 12-69.

The standard governing the extrusion compounds used in the manufacture of polyethylene pipe is ASTM* 1248-70. This standard categorizes polyethylene extrusion compounds into four types based on density. ASTM Type I PE has a density range of 0.910 to 0.925 grams/cubic centimeter (g/cc) while Type II has a density range of 0.926 to 0.940 g/cc. Type III PE has a density range of 0.941 to 0.959 g/cc and Type IV encompasses all resins with densities of 0.960 g/cc or greater.

A coding system has been devised (and is stamped on ASTM compliant pipe) which imparts several important pieces of information to the user. This coding system uses a four-digit number—the first digit refers to the ASTM type, the second refers to the ASTM grade, and the last two specify the hydrostatic design stress (used in the determination of pipe pressure rating) in units of 100 psi.

Table 1 lists the most frequently used ASTM PE Types used in the manufacture of PE pipe, the four-digit code, and the hydrostatic design stress.

The pressure rating of any plastic pipe may be calculated from its hydrostatic design stress by using the following equation:

$$P = \frac{2s}{(D/t) + 1}$$

where S = hydrostatic design stress (psi)
P = pressure rating (psi)
D = inside diameter (in.)
t = minimum wall thickness (in.)

The value (D/t) is held constant in the manufacture of most plastic pipe and is called the standard thermoplastic pipe dimension ratio (SDR). For polyethylene pipe, the inside diameter is used to compute the SDR: the outside diameter is used to compute the SDR or PVC and ABS pipe. The SDR system enables the user to select a number of different sizes of pipe for a piping system, all of which will have the same design pressures. Table 2 shows the water pressure ratings for the four common PE pipe materials for the five common SDRs.

* American Society for Testing and Materials

Table 1
Hydrostatic Design Stresses of Common Polyethylene Pipe Materials (ASTM 2239, App. A)

ASTM Type	ASTM Code Number	Hydrostatic Design Stress
I, Grade 4	1404	400 psi
II, Grade 3	2305	500 psi
II, Grade 3	2306	630 psi
III, Grade 3	3306	630 psi

Table 2
Water Pressure Ratings of Standard Dimension Ratio Polyethylene Plastic Pipe (ASTM 2239)

	Water Pressure Rating (psi) at 23°C			
	PE Pipe Materials			
SDR	PE 3306	PE 2306	PE 2305	PE 1404
5.3	200	200	160	125
7	160	160	125	100
9	125	125	100	80
11.5	100	100	80	
15	80	80		

Polyethylene pipe is also manufactured in Schedule 40 and 80 sizes.* Table 3 lists the water pressure ratings of the Schedule 40 and 80 PE pipe.

Polyethylene pipe is produced in sizes from 1/2 in. to 12 in. The major advantage of PE pipe is its flexibility. It may be coiled in extremely long lengths from 100 ft to 2000 ft on special order; this makes it easy to install using a minimum number of fittings. This flexibility which permits moderate changes in direction without kinking or the need for fittings, allows it to be installed in curved trenches.

* Schedule numbers relate to allowable stress for the material of manufacturer to the internal working pressure as follows:

$$\text{Schedule number} = \frac{(1000)\ (\text{internal pressure})}{(\text{allowable stress})}$$

For pipe less than 8 in. in diameter only Schedule numbers 40, 80, 120, and 160 are used.

The major disadvantage to polyethylene pipe is its relatively low hydrostatic design stress and poor rigidity. The maximum ambient temperature for polyethylene is less than 140°F. In its natural state, it is sensitive to light and is embrittled on exposure to ultraviolet irradiation. This is offset, however, by the addition of 2–2.5% carbon black during compounding.

The most popular method of joining polyethylene pipe is with insert fittings and stainless steel clamps, although fusion welding of the pipe to the fittings is also an acceptable practice. Exclusive use of insert fittings in a multi-joint, multi-fitting installation may result in significant pressure drop unless high-density flare pipe and flare fittings are used.

Acrylonitrile-Butadiene-Styrene (ABS). ABS material is generally used in pipe and fittings for potable water and drain, waste and vent (DWV) systems. ABS pipe offers excellent impact resistance, even at low temperature and has good dimensional stability. It is one of the higher heat-resistant plastics with a temperature limitation just under 160°F. It is generally considered a rigid pipe although when manufactured in thinner walls, it is often referred to as semi-rigid.

ABS pipe is produced in accordance with Product Standards (PS) 18-69 and PS 19-69.

The ASTM resin types for ABS materials are shown in Table 4. The resin type is a function of the impact strength and the grade is a function of the deflection temperature under load. Pipe extruded in accordance with Product Standards to specific dimension and tolerance specifications will, regardless of resin type, produce equally strong pipe. Tables 5, 6, and 7 summarize the sizes and pressure ratings of ABS plastic pipe.

Among the advantages of ABS pipe: it has good chemical resistance to non-oxidizing chemicals; it has high heat resistance and relatively high hydrostatic design stress; it is tough and resistant to impact; it can be joined by solvent welding, or when wall thicknesses are adequate, it can be threaded with standard pipe threads; it is light-weight and relatively easy to handle. Among ABS pipe disadvantages: it is available in relatively short lengths (normally 20-ft lengths); it is subject to organic solvents, and is not as flexible as polyethylene; its impact strength and elongation properties are materially decreased upon exposure to sunlight. (Carbon black is usually added to the ABS compounds to minimize the effects of ultra-violet exposure.)

Polyvinyl Chloride (PVC). PVC, like ABS, is commonly used in pipe and fittings for both potable water and DWV systems. PVC pipe is considered rigid with an operating temperature limitation of approximately 150°F. PVC potable water pipe is manufactured in conformance with Product Standard 21-70.

Table 3
Water Pressure Rating, Polyethylene Plastic Pipe Schedules 40 and 80 (ASTM D 2447)

Nominal Pipe Size (in.)	Pressure Rating (in psi) at 23°C*					
	PE2306 PE3206 PE3306		PE2305		PE1404	
	Sch 40	Sch 80	Sch 40	Sch 80	Sch 40	Sch 80
1/2	188	267	149	212	119	170
3/4	152	217	120	172	96	137
1	142	199	113	158	90	126
1 1/4	116	164	92	130	74	104
1 1/2	104	148	83	118	66	94
2	87	127	69	101	55	81
2 1/2	96	134	76	106	61	85
3	83	118	66	94	53	75
3 1/2	75	109	60	86	50	69
4	70	102	55	81	NPR	65
5	61	91	50	82	NPR	58
6	55	88	NPR	70	NPR	56
8	50	...	NPR	...	NPR	...
10	NPR**	...	NPR	...	NPR	...
12	NPR	...	NPR	...	NPR	...

* These pressure ratings apply only to unthreaded pipe. The industry does not recommend threading PE plastic pipe.
** NPR = not pressure rated. The industry does not recomsure ratings less than 3.52 kgf/cm² (50 psi).

Table 4
Hydrostatic Design Stresses of Common ABS Pipe Materials

ASTM Type	ASTM Code Number	Hydrostatic Design Stress
I, Grade 1	1106	630 psi
I, Grade 1	1108	800 psi
I, Grade 2	1208	800 psi
I, Grade 2	1210	1000 psi
I, Grade 3	1316	1600 psi
II, Grade 1	2112	1250 psi

Table 5
Water Pressure Rating of Schedule 40 ABS Plastic Pipe (ASTM D 1527)

Nominal Pipe Size (in.)	Pressure Ratings (psi) at 23°C*			
	ABS 1208	ABS 1210	ABS 1316	ABS 2112
1/8	320	400	650	500
1/4	310	390	620	490
3/8	250	310	500	390
1/2	240	300	480	370
3/4	190	240	390	300
1	180	220	360	280
1 1/4	150	180	290	230
1 1/2	130	170	260	210
2	110	140	220	170
2 1/2	120	150	240	190
3	100	130	210	160
3 1/2	90	120	190	150
4	90	110	180	140
5	80	100	160	120
6	70	90	140	110
8	60	80	120	100
10	60	70	110	90
12	50	70	110	80

* These pressure ratings are for unthreaded pipe. The industry does not recommend threading ABS plastic pipe in Schedule 40 dimensions. All pressure ratings are calculated from hydrostatic design stresses based on test data obtained in tests made on 1/2 to 2-in. pipe.

ASTM 1755 is the standard specification for polyvinyl chloride resins. ASTM Type I PVC resins are materials with high resistance to chemicals and the Type II resins possess high impact characteristics.

The ASTM designations for PVC are shown in Table 8.

Once again, the extrusion of PVC pipe in accordance with Product Standards ensures that the working pressures for a given schedule or pressure rating are comparable. Tables 9, 10, 11, and 12 summarize the sizes and pressure ratings of various PVC pipes.

Among PVC pipe's advantages are dimensional stability and excellent weathering characterstics. PVC is extremely resistant to chemicals and oils and has excellent mechanical strength and rigidity. PVC is self-extinguishing when ignited and is extremely heat resistant.

A disadvantage is the short lengths commonly available (20 ft). Also, it is readily softened by the ether, ketones, and chlorinated hydrocarbons, and is a heavy material, compared to ABS and PE.

It can be joined by fusion welding, solvent weld-

Table 6
Water Pressure Rating of Schedule 80 ABS Plastic Pipe ASTM D 1527

Nominal Pipe Size (in.)	Pressure Ratings (psi) at 23°C							
	ABS 1208		ABS 1210		ABS 1316		ABS 2112	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
1/8	...	...	...	...	980	490	...	...
1/4	...	...	...	...	900	450	...	...
3/8	...	...	...	...	730	370	...	...
1/2	340	170	420	210	680	340	530	260
3/4	280	140	340	170	550	280	430	210
1	250	130	320	160	500	250	390	200
1 1/4	210	100	260	130	420	210	330	160
1 1/2	190	90	240	120	380	190	290	150
2	160	80	200	100	320	160	250	130
2 1/2	170	80	210	110	340	170	270	130
3	150	70	190	90	300	150	230	120
3 1/2	140	70	170	90	280	140	220	110
4	130	60	160	80	260	130	200	100
5	120	60	140	70	230	120	180	90
6	110	60	140	70	230	120	180	90
8	100	50	120	60	200	100	150	80
10	90	50	120	60	190	90	150	70
12	90	50	110	60	180	90	140	70

Table 7
Water Pressure Rating of Standard Dimension Ratio (SDR) Nonthreaded ABS Plastic Pipe
ASTM D 2282

	Pressure Rating (in psi) at 23°C			
SDR	ABS 1316	ABS 2112	ABS 1210	ABS 1208
13.5	250	200	160	125
17	200	160	125	100
21	160	125	100	80
26	126	100	80	

Table 8
Hydrostatic Design Stresses of Common PVC Pipe Materials
ASTM D 1785

ASTM Type	ASTM Code Number	Hydrostatic Design Stress
I, Grade 1	1120	2000 psi
I, Grade 2	1220	2000 psi
II, Grade 1	2110	1000 psi
II, Grade 1	2112	1250 psi
II, Grade 1	2116	1600 psi

ing, and can be readily threaded if the wall thickness permits.

Solvent Cements. The cements used when PVC and ABS pipe and fittings are joined by solvent cementing techniques consist of fine particles of plastic material dissolved in a solvent system. The plastic material used in the cement for a specific application must be the same as that of the pipe to be joined. Solvent systems used in solvent cements vary in content and relative proportion of constituents. They usually contain a major proportion of a solvent which will dissolve the pipe material (e.g., tetrahydrofuran or methylethyl ketone for PVC) and one or more other solvents which alter the evaporation rate of the principal solvent. The solvent system serves a dual function in the making of a solvent-cemented joint: it acts as a vehicle for the dissolved plastic material in the cement as well as an etchant which acts on the surface of the parts to be joined. As the solvent evaporates after application of the cement to the joint, the dissolved plastic material is deposited in the annulus between the pipe and the fitting. The etched, rough surfaces to be joined accept the plastic material, resulting in a strong joint. The ability to vary the composition of the solvent system is a tremendous advantage for it allows the user to mitigate the climatic conditions in which the joints are to be made. In a low temperature environment the single major solvent may be used, or evaporation enhancing solvents may be added to allow optimum evaporation of the solvent system. Prolonged contact between the solvent system and the materials to be joined might result in the etching of a plane of weakness in the joint. In a hot, arid climate, the principal solvent might evaporate so rapidly that insufficient etching and an improper bond would result. This condition could be mitigated by the incorporation of a less volatile solvent into the solvent system.

Solvent cements meeting the requirements of the following specifications will produce satisfactory joints when properly applied:

ASTM D 2235 Solvent Cement for ABS Pipe and Fittings.

ASTM D 2564 Solvent Cement for PVC Pipe and Fittings.

Solvent cement joining procedures are not recommended for PE pipe.

Mechanical Characteristics. Knowledge of the materials and methods of manufacture of the finished plastic pipe is essential for proper design of a plastic piping system. The following discussion details the manufacturing processes and the properties peculiar to plastic pipe.

Manufacture of Plastic Pipe. All thermoplastic pipe is manufactured by an extrusion process; fittings are manufactured by an injection mold process. Pellets of plastic materials are heated under pressure and forced through a shaping die to conform to the dimensional requirements of the piping product. The product is then slowly cooled and further shaped through sizing devices to make its dimensions comply with standards.

Most plastic pipe is manufactured from virgin materials, but the standards allow the use of rework materials (only within the same production plant) as long as the pipe product is of equal quality to that extruded from virgin material. The raw materials used in the manufacture of thermoplastic pipe and fittings are products of petrochemical technology and basically consist of extremely long hydrocarbon molecules.

By combining various ingredients, an unlimited range of materials and physical properties can be generated. The thermoplastic materials commonly used in water service and distribution lines are selected for this

Table 9
Water Pressure Ratings of Schedule 40 PVC Plastic Pipe ASTM D 1785

Nominal Pipe Size (in.)	Pressure Ratings (in psi) at 23°C*: PVC 1120 PVC 1220	PVC 2116 CPVC 4110	PVC 2110	PVC 2112
1/8	810	650	400	500
1/4	780	620	390	490
3/8	620	500	310	390
1/2	600	480	300	370
3/4	480	390	240	300
1	450	360	220	280
1 1/4	370	290	180	230
1 1/2	330	260	170	210
2	380	220	140	170
2 1/2	300	240	150	190
3	260	210	130	160
3 1/2	240	190	120	150
4	220	180	110	140
5	190	160	100	120
6	180	140	90	110
8	160	120	80	100
10	140	110	70	90
12	130	110	70	80

* These pressure ratings apply only to unthreaded pipe. The industry does not recommend threading PVC plastic pipe in Schedule 40 dimensions in nominal pipe sizes 150 mm (6 in.) and smaller.

application. They are based on a favorable combination of physical and economic properties to ensure a system of long life at low initial and maintenance costs. Plastic pipe is subjected to the rigid tests during manufacture.

Allowable Stresses. Maximum design stresses for the three types of piping materials considered in this study have been given earlier. The stress levels given are the maximum for the resultant stresses from hydrostatic and mechanical loads, including the effects of hydraulic surges. Load and stress analysis for plastic piping systems can be performed with conventional analytical methods.

Thermal Expansion of Plastic Pipe. The coefficients of thermal expansion of thermoplastic materials are much greater than those of metals, being on the average at least five times (and in some cases as much as twenty times) that of steel. The magnitude of linear expansion associated with such coefficients can be appreciated by noting that a 100-ft length of Type I PVC, if installed at 75°F, would expand approximately 2 in. if its operating temperature were 135°F, or would contract approximately 2 in. if its operating temperature were 10°F.

In general, linear movement resulting from thermal

Table 10
Water Pressure Ratings of Schedule 80 PVC Plastic Pipe ASTM D 1785

Nominal Pipe Size (in.)	Pressure Ratings (psi) at 23°C: PVC 1120	PVC 1220	PVC 2116		PVC 2110		PVC 2112	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
1/2	850	420	680	340	420	210	530	260
3/4	690	340	550	280	340	170	430	210
1	630	320	500	250	320	160	390	200
1 1/4	520	260	420	210	260	130	320	160
1 1/2	470	240	380	190	240	120	290	150
2	400	200	320	160	200	100	250	130
2 1/2	420	210	340	170	210	110	260	130
3	370	190	300	150	190	90	230	120
3 1/2	350	170	280	140	170	90	220	110
4	320	160	260	130	160	80	200	100
5	290	140	230	120	140	70	180	90
6	280	140	220	110	140	70	170	90
8	250	120	200	100	120	60	150	80
10	230	120	190	90	120	60	150	70
12	230	110	180	90	110	60	140	70

Table 11
Water Pressure Ratings of Schedule 120 PVC Plastic Pipe
ASTM D 1785

Nominal Pipe Size (in.)	Pressure Ratings (psi) at 23°C							
	PVC 1120	PVC 1220	PVC 2116		PVC 2110		PVC 2112	
	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded	Unthreaded	Threaded
1/2	1010	510	810	410	510	250	630	320
3/4	770	390	620	310	390	190	480	240
1	720	360	570	290	360	180	450	220
1 1/4	600	300	480	240	300	150	370	190
1 1/2	540	270	430	210	270	130	340	170
2	470	240	380	190	240	120	290	150
2 1/2	470	230	370	190	230	120	290	150
3	440	220	360	180	220	110	280	140
3 1/2	380	190	310	150	190	100	240	120
4	430	220	340	170	220	110	270	130
5	400	200	320	160	200	100	250	120
6	370	190	300	150	190	90	230	120
8	380	180	290	140	180	90	230	110
10	370	180	290	140	180	90	230	110
12	340	170	270	140	170	80	210	110

strain does not present a serious problem for either buried piping or piping within a structure, because the high coefficients of thermal expansion are compensated for by the low moduli of elasticity of thermoplastic materials. Thus, the piping can undergo appreciable expansion without inducing excessive axial stresses. Normally, thermal expansion is not a consideration when the overall temperature range is less than 30°F, even for thermoplastic materials having the highest coefficients of expansion.

Thermal expansion for installations exposed to extreme temperature changes may be determined from Table 14. The linear extension shown is independent of the diameter.

Methods of Joining. The most common methods of joining plastic piping are with insert fittings and hose clamps, threaded connections, flanging cementing, fusion, and welding. Flared connections are also possible, but are not recommended for field use because of the high degree of skill required to achieve a satisfactory flare. Some manufacturers have marketed gasketted bell and spigot joints for plastic pipe, but as yet no standards exist for such joints. Fusion joining and welding are not generally recommended for field use because of the close temperature control required over the surfaces being jointed.

Serrated Insert Fittings and Hose Clamps. The simplest method of joining PE plastic pipe and fittings uses serrated insert fittings and hose clamps. This method is commonly used to join polyethylene pipe and

Table 12
Water Pressure Rating of Standard Dimension Ratio (SRD) ASTM D 2241

SDR	Pressure Ratings (in psi) at 23°C*			
	PVC 1120 PVC 1220	PVC 2116 CPVC 4116	PVC 2112	PVC 2110
13.5	315	250	200	160
17	250	200	160	125
21	200	160	125	100
26	160	125	100	80
32.5†	125	100	80	63
41**	100	80	63	50
64††	63	50	NPR***	NPR***

* These pressure ratings do not apply for threaded pipe.
† Available only in nominal pipe size diameters of 3 to 12 in.
** Available only in nominal pipe size diameters of 3 1/2 to 12 in.
†† Available only in nominal pipe size diameters of 6 to 12 in.
*** Not pressure rated.

Table 13
Summary of Characteristics of Plastic Piping Materials

Material	Properties	Applications	Maximum Operating Temperature	Joining Methods	Standards
PE Polyethylene Low, Medium and High Density	Good chemical and crush resistance Excellent impact strength and flexibility High level elongation at freezing Good low temperature performance Non-toxic NSF approved for potable water	Low pressure water systems distribution Irrigation and golf course sprinkler system Corrosive liquids & gasses Underground conduits and gas liners Industrial and chemical laboratory drainage systems Natural gas Water service Distilled and demineralized water	120°F 200°F	Insert fittings Butt welding Heat fusion External compression fittings Transition fittings	PE PS 10-69 PS 11-69 PS 12-69 ASTM D 2104, ASTM D 2239, ASTM D 2447, ASTM D 2513, F-S 00545, MIL-P26692, MIL-P22634.
ABS Acrylonitrile-Butadiene-Styrene	Good chemical resistance to household chemicals Good crush resistance Non-toxic NSF approved for potable water and DWV Rigidity at higher temperatures Excellent impact strength especially at low temperature Fast-setting joints	DWV piping systems—mobile and residential Pressure piping and drainage systems Water service Irrigation, industrial and municipal Gas service Underground electrical conduit	180°F	Solvent welding Transition fittings	ABS PS 18-69, PS 19-69, ASTM D 1527, ASTM D 2282, ASTM D 2465, ASTM D 2468, ASTM D 2469, ASTM D 2513, F-S 322, FHA-MPS Rev. No. 31, IAPMO TSC 6-61, TSC 3-62, IAPMO PS 17-65, IS 5-65.
PVC Polyvinyl Chloride	Excellent chemical resistance Good crush and impact strength Fire-resistant (self/extinguishing) High tensile strength Non-toxic NSF approved for potable water and DWV	DWV piping systems Pressure piping and drainage systems Water and gas distribution Irrigation and golf course sprinkler systems Sewage treatment Above and underground conduit Industrial chemical piping Corrosive fume ducting Crude oil flow lines Water well casing	150°F 180°F	Solvent welding Threaded Flanged Compression fittings O-rings Transition fittings Bell-ring Rubber gasket	PVC PS 21-70, ASTM D 1785, ASTM D 2241, ASTM D 2464, ASTM D 2466, ASTM D 2467, ASTM D 2513, F-S 320, F-S 540, MIL-P 22011, FHA-MPS Rev. No. 31, FHA UM 41.

Table 14
Thermal Expansion of Plastic Piping

Length of Pipe (ft)	Length Change (in.) for Indicated Temperature Changes						
	40°F	50°F	60°F	70°F	80°F	90°F	100°F
20	.221	.276	.331	.386	.442	.497	.552
40	.442	.552	.662	.773	.882	.994	1.104
60	.662	.828	.994	1.160	1.325	1.490	1.656
80	.883	1.104	1.325	1.546	1.766	1.987	2.208
100	1.104	1.380	1.656	1.932	2.208	2.484	2.760

works best with the low density type of material which is soft and flexible. Although high density polyethylene has been successfully joined with insert fittings, more difficulty must be expected in making tight joints because of the greater stiffness of the pipe. To obtain a good seal, the insert fittings must be handmade; they are commonly made of acrylonitrile-butadiene-styrene polymer, nylon, or high impact styrene.

Stainless steel hose-type screw clamps are recommended to minimize corrosion of the clamps, and they are generally recommended for buried polyethylene piping systems.

Threading. This method is useful when the pipeline must be disassembled frequently for cleaning or inspection. Threaded connections are recommended only for pipe schedules 80 to 120. Threads can be cut in plastic pipe by machine or by hand with standard metal thread-cutting tools to mate with the standard internal thread of molded fittings and valves. When threading the pipe, however, only thread tape or lubricant recommended by the pipe manufacturer should be used. Conventional pipe thread compounds, putty, oil-base products, or unknown mixtures should be avoided.

Since plastics are relatively flexible, it is considered good practice to insert a long tapered plug in the end during threading to prevent crushing or rupturing of the pipe wall.

When assembling a threaded joint, it is first made hand tight; additional torque may be applied with a strap wrench. Standard pipe wrenches should not be used because they will deform and scar the pipe surface.

When threaded joints are made between plastic and metal piping, the difference in thermal expansion suggests the use of female plastic components and male metal components to insure lead tightness.

Flanged Joints. These are most often used where lines must be frequently disassembled. Flanges are made to standard dimensions to facilitate joining plastic and metallic piping systems and are available commercially with both socket and threaded pipe-to-flange connections.

Gaskets used in flanged connections are normally made of neoprene, tetrafluorethylene, or rubber materials. The use of a torque wrench for tightening flange bolts is required to assure that the flange is evenly loaded. Because of creep, however, it is necessary to periodically check the loading of bolts in flanged joints to assure tight joints.

Solvent Cementing. Solvent-cemented joints using socket or slip sleeve fittings can be used with many different types of thermoplastic pipe. Filled solvent cements contain dissolved pipe material, thus it is necessary to use the proper joining compound with a given type of plastic piping.

When making the joint, it is good practice to clean the mating surface with a suitable solvent (as recommended by the pipe manufacturer) to assure the deposit of a uniform coating of cement. When this solvent has dried, cement is applied quickly to the fitting and pipe.

The pipe is then immediately inserted in the socket and given a 1/4 to 1/2 circumferential turn to further assure uniform distribution of the solvent in the joint, and to dispel any entrapped air. Excess cement must be wiped off to avoid a reduction in pipe strength due to solvent etching. When the filled cements cure, the solvent evaporates, and the dissolved piping material remains to fill the voids and insure a good bond. Solvent-cemented joints can normally be handled in 10 to 15 min., but require for 24 to 48 hours to acquire full strength, depending upon ambient conditions. Once the joint is cured, its strength should equal that of the pipe.

When making up a solvent cement joint, the fit of the joint between pipe and fitting should be tested before cementing. Experience indicates that the optimum diametral gap (the difference between the inside diameter of fitting and the outside diameter of pipe) should be about 0.020 to 0.025 in. However, good solvent-cemented joints may be obtained with clear-

ance up to 0.040 in. Thus, if inspection prior to cementing shows that the pipe and fitting fit loosely together, it is recommended that the fitting not be used. The advantages of solvent-cemented joints which have led to their widespread use are the ease with which joints can be made, and the greater assurance of strong and leak-free joints. Additionally, since the joint does not weaken the pipe, as in the case of threading, a thinner wall section can be used for a given working pressure. The major drawback of solvent-cement joints is that they cannot be disassembled. However, wherever possible, and if the pipe is compatible with this method of joint, solvent cementing should be used.

Heat Fusion. These joints are made by heating mating surfaces to their fusion temperature and then bringing the surfaces into contact with one another. Direct application of heat using a torch, or other open flame, is prohibited.

The operator must possess a high degree of skill, and close temperature control is needed to obtain quality heat fusion joints. Care must be exercised to prevent overheating of the material or insufficient heating which will not adequately soften the material. Procedures specified by the Plastic Pipe Institute should be followed.

Two general methods of heat fusion are used. Socket fusion consists of simultaneously heating both the external surfaces of the pipe end and the internal surface of the socket in the fitting until the material reaches fusion temperature, inserting the pipe end into the socket with a slight turning motion, and allowing the joint to cool. Butt fusion consists of heating the square-cut ends of matching butt surfaces by holding them against a heating plate until fusion temperature is reached, then pushing the two soft ends against one another and allowing the joint to cool. This method is best used on thick-walled pipe.

Heating tools must be capable of maintaining uniform surface temperature within the specified melt-temperature range. Some type of temperature indicator must be used to measure tool surface temperature. Temperature devices should be periodically calibrated.

Most plastics tend to stick to the heating tool when hot. This situation may be minimized by coating the contact surfaces with polytetra-fluorethylene (PTFE) or PE mold release agents recommended by the manufacturer.

Thermal Welding. Thermal welding of socket joints can be accomplished effectively with polyethylene and polyvinyl chloride pipe material; however, this method of joining requires greater skill and training of the operator. Welding is accomplished by heating the pipe and a filler rod, which should be made of the same material as the pipe, by means of a stream of hot gas. A more recent development for heat sealing of pipe and socket-type fittings employs electric heater elements which simultaneously bring the outside of the pipe and the inside of the socket fitting to the proper temperature for fusion of the mating surfaces. In both methods the temperature is critical, and poor joints result if the temperature is not maintained within narrow limits.

Heated air can be used for some plastics, with the hot-gas welding technique, but for others an inert gas is required to prevent oxidation and poor welds. When welding polyethylene and polypropylene, oxidation products which occur immediately following extrusion must be scraped away to assure satisfactory results.

Compression Couplings. Compression couplings similar to those used with steel pipe or copper tubing may be used with plastic pipe; however, they are not recommended. Since plastics are subject to the phenomenon of cold flow at ambient temperatures and relatively low stress levels, it is necessary to reinforce the plastic pipe that is subjected to the compressive force exerted by the wedge gasket of a compression-type coupling. A rigid tubular insert that is made to close tolerance with the inside diameter of the plastic pipe is used for this purpose. This insert is usually a metallic cylindrical section 1 1/2 or 2 times the stab depth in length. It should not be slit or slatted and should be free of rough or sharp edges which could cut into the plastic materials. The rubber gasket material in the coupling must be compatible with the plastic pipe.

When the joint is assembled and tightened it must effectively sustain longitudinal pull-out forces caused by thermal contraction of the piping and by external loading forces. This has been the cause of many operational problems. Care must be taken not to overtighten the nut on the plastic pipe side of the coupling. One and one-half to two full turns of the nut beyond hand-tight is usually sufficient. Metallic rings or gasket armoring, which cut or appreciably penetrate the plastic, should not be used without a thorough investigation of the effects on long-term service performance.

Methods of Cutting and Shaping. Plastic pipe can be easily cut with an ordinary carpenter saw or hacksaw. Fine tooth blades are recommended. The pipe should

be cut square and all burrs should be removed with a sharp knife or fine-tooth file. A miter box is useful to insure square cut ends.

Special cutters with extra wide rollers and a thin cutting wheel have been designed for cutting certain kinds of plastic pipe. Regular pipe cutters may be used on plastic pipe provided the cutting wheel has been changed to the type recommended by the pipe supplier.

Only polyethylene piping is considered flexible enough to conform to natural contours, and this only in diameters up to 2 in. For this size, a 20 in. radius is recommended for a 90° bend. Rigid and semi-rigid pipe may be bent, but field bending requires such a degree of skill that this method of directional change is not recommended. Use of fittings is recommended to achieve directional change. Should the requirement arise for the bending of pipe in the field, the following procedures can be used. However, great care should be taken during this exercise.

Both ends of the pipe length are sealed with plumber's test plugs and sufficient air pressure introduced to keep the pipe oval during bending. Also, the pipe can be filled with preheated sand. The pipe is then heated uniformly by immersion in hot oil or water, or by rotation in front of a hot air gun. An open flame should not be used. When the pipe becomes soft and pliable, it should be placed in a wooden forming jig or form. The bend should be made as quickly as possible to prevent weakening or deforming the pipe. The minimum radius to which a bend should be made is five to six pipe diameters, but the first forming bend should be slightly greater to allow for springback. The bend should be kept in the forming jig until the pipe cools and becomes rigid; then it should be immersed in water. Air pressure should not be relieved or sand removed until final cooling.

Obviously, bending plastic pipe is not a simple operation. If a design calls for many field bends, installation costs will be substantially increased.

Resistance to Degradation.

Fungi. The term fungi refers to a family of heterotrophic plant life made up of molds, mildews, and mushrooms. Completely lacking in chlorophyl, they are unable to derive energy directly from sunlight. Rather, they derive energy from organic materials such as carbohydrates, which are particularly good nutrient for fungi.

Fungi thrive in a warm, humid atmosphere and are most abundant in, but by no means limited to, tropical areas. Temperatures of 25–30°C and relative humidites of 85–100% are most favorable, although certain fungi have been found to exist at much lower temperatures. Although fungi show very little active growth at relative humidities below 65–70%, they can survive extended periods of exposure to low humidity.

Because of extensive loss of military equipment caused by fungi in tropical areas during World War II, considerable studies were made on the effect of fungi on plastics compounds.[1,2,3,4,5] From the literature surveyed, it is apparent that the growth of fungi on plastics is not due to the nutrient value of the polymer or resin component, but rather to lower molecular weight additives such as lubricants, stabilizers, and plasticizers. In the case of highly plasticized (flexible) vinyl chloride plastics, however, attack by fungi is avoided if proper attention is paid to the selection of plasticizer and other additives.[6,7,8]

Thermoplastic materials used for the manufacture of pipe contain little (if any) non-polymeric material. They have a high degree of resistance to attack by fungi because of the lack of nutrients in their compositions. Despite the minimal nutritive value in most plastic pipe materials, fungi may grow upon pipe surfaces, feeding upon contaminants which may settle on the surface. Such surfaces are generally not attacked, or suffer only slight surface etching.

Bacteria. Bacteria in general require a wetter environment than fungi for active growth. Some forms of bacteria (aerobic) require the presence of oxygen to sustain life, while others (anaerobic) grow only where there is no oxygen. Still others exist whether oxygen is

[1] C.J. Wessel, "Biodegradation of Plastics," *SPE Transactions*, Vol 4, No. 3 (1964), pp. 193–207.
[2] H. Kuhlwein and F. Demmer, "The Microbial Corrosion of Plastics," translation from *Kunststoffe*, Vol 57 (1967), pp. 183–188.
[3] Sidney Levy, "Designing for Environmental Resistance," *Plastics World*, Vol 20, No. 5 (1962), pp. 22–25.
[4] F.E. Kulman, "Microbiological Deterioration of Buried Pipe and Cable Coatings," *Corrosion*, Vol 14 (1958), pp. 213–2225.
[5] W.H. Stahl and Helmut Pessen, "Funginertness of Internally Plasticized Polymers," *Modern Plastics* (1954), pp. 111–112.
[6] Wessel, pp. 193–207.
[7] Kuhlwein and Demmer, pp. 183–188.
[8] Stahl and Pessen, pp. 111–112.

present or not. Since bacteria of many forms are encountered in nearly all areas where water is present, it is to be expected that when pipe is installed in wet areas, it will come in contact with one or more forms of bacteria. However, laboratory tests show that the interaction between plastics and bacteria is the same as that between plastics and fungi. Plastic pipes contain no nutrients and are resistant to attack.[9,10,11,12,13,14]

There have been instances cited in which rigid PVC stabilized with lead compounds has been discolored when buried in mud under sea water. The discoloration has been attributed to hydrogen sulfide produced by anaerobic, sulfate-reducing bacteria. Even under these conditions, there were no indications that the mechanical properties of the material were changed.

Termites. Termites are found world-wide and are known to cause extensive damage to wood. In tests of the resistance of plastic pipe to termites and other insects, pipe samples have been buried in termite-infested soil and periodically dug up and examined. In one test, the area contained decayed pine logs infested with termites. Pine strips were placed between the polyethylene pipe samples to serve as bait. The soil was covered with logs which contained termites. At the end of eighteen months, the pipe was uncovered. There was no attack by termites, fungi, insects, or any other biological agent, and the pipe was in excellent condition although the pieces of pine wood buried with the pipe were infested with termites and heavily decayed by fungi. In another test, PVC pipe samples were exposed to termites for five years without attack on the pipe.

There has been termit attack reported on plastic film and wire and cable insulation in Europe, Africa, and Australia,[15,16] where the species of termites seems especially destructive. In general, plastics used in these applications are softer and often highly plasticized, in contrast to those plastics used in pipe. Furthermore, the larger size of pipe vs. electrical insulation makes the pipe more resistant to attack. In one report[17] it was found that termites chewed on plastic, even though they could not use it as food. It is believed that in some cases "worker" termites burrow through soil, and anything else their jaws can handle, in search of food.

Rodents. All materials except the hardest metals, concrete, and similar materials can be gnawed by rodents. There have been instances where plastic pipe has been damaged by rodents, but these are so random that it appears rodents are neither attracted to nor repelled by plastic pipe. They simply gnaw it when it gets in their way or when they are looking for water. The period when the pipe is newly installed and soil is loose around the pipe makes an attractive burrowing area for rodents. However, there is evidence that rodent repellents added to the fill in the trench are effective in minimizing such damage.

Installation Techniques and Constraints. In general, satisfactory installations of plastic piping will result from following the procedures called for in the Plastic Pipe Institute *Installation Procedures,* as supplemented by ASTM and NSF publications and specific recommendations of manufacturers. Some particular points, however, should be noted.

For underground installation, trenches at any point below top of pipe should be excavated to the minimum width required for proper installation and to the required depth with straight sides. The bottom should be smooth, having a uniform grade, and should have a bedding layer of compacted fine soil or sand placed in the bottom. The pipe should be placed in the ditch so that the pipe bears on the bedding throughout the entire length of the pipe barrel. The trench should then be backfilled with the same soil material of which the bedding is made to a depth of at least 12 in. above the elevation of the top of the pipe, and care should be taken to thoroughly compact the backfill under the haunches of the pipe; the 12-in. backfill immediately above the pipe should not be compacted. To minimize damage during the backfill, the pipe should be brought up to operating pressure during backfilling.

[9] Wessel, pp. 193–207.

[10] Kuhlwein and Demmer, pp. 183–188.

[11] Levy, pp. 22–25.

[12] R.A. Connolly, "The Effect of Seven-Year Marine Exposure on Organic Materials," *Materials Research and Standards* (1963), pp. 193–201.

[13] Lloyd R. Snoke, "The Resistance of Organic Materials and Cable Structures to Marine Biological Attack," *The Bell Technical Journal* (1957), pp. 1095–1126.

[14] Priscilla L. Steinberg, "Resistance of Organic Materials to Marine Bacterial Attack," *Developments of Industrial Microbiology* (Plenum Press, 1961), Vol 2, pp. 271–281.

[15] Victor W. Harris, "Termites in Europe," *New Scientist*, Vol 13 (1962), pp. 614–617.

[16] F.J. Gay and A.H. Wetherly, *Laboratory Studies of Termite Resistance: The Termite Resistance of Plastics*, Division of Etomology Technical Paper No. 5 (Commonwealth Scientific Research Organization, 1962).

[17] Harris, pp. 614–617.

Backfill and bedding should be of selected fine compactible soil materials free of stones, boulders, sharp objects or waste which could form organic acids. Both backfill and bedding should be compacted at near optimum moisture content in layers not exceeding 6 in. (compacted thickness) to a density of at least 90% of the maximum.

When piping is not insulated, the piping should be installed at a depth of not less than 12 in. below the frost line.

Below-grade piping should be installed to allow for expansion and contraction. Allow pipe to cool to service temperature before backfilling.

When piping is buried, thermal expansion can normally be accommodated by snaking the pipe as it is laid in the trench. For larger diameters, it is most often necessary to place the pipe in the ditch with some care to achieve the snaking effect; offsets, and mechanical expansion joints can be used if necessary.

Considering the most stringent combination of minimum and maximum ambient temperatures likely to be involved (0° and 130°F, respectively) as well as the likely range of water service temperatures, then: (1) below-grade piping should be installed to allow for the expansion and contraction which would occur over a temperature differential of 100°F, and (2) cold-water lines above grade should be installed to allow for the expansion and contraction which would occur over a temperature differential of 130°F.

A note of caution should be expressed with respect to piping that must be placed along a trench and left exposed for hours during the heat of day. Many thermoplastic materials, when exposed to direct sunlight, expand considerably. If the piping is installed and covered while in this expanded state, there can be substantial contraction with serious consequences when the pipe reaches the minimum ground temperature anticipated. One method of guarding against this effect is to allow the pipe to cool overnight, then backfill the trench in the morning. Another method is to put a complete section of piping into service before backfilling; this allows the conveyed water to cool the pipe to a temperature within the range to be encountered in service.

All underground piping should be tested before backfilling.

Fittings used at changes in direction will require thrust backing which must be formed against solid trench wall. Hand digging should be employed at these locations to assure undisturbed solid trench wall for thrust backing.

When buried plastic pipe is to be subjected to heavy dynamic surface loads such as traffic, no special measure other than minimal burial depth of 24 in. is required in areas of heavy overhead traffic; a minimum depth of 18 in. is required in areas of light overhead traffic. Where the minimum depths cannot be attained or special conditions require additional protection of the piping, the plastic pipe should be laid in a conduit having at least a 50% larger diameter. The larger conduit may be metal or reinforced plastic, but care must be taken to ensure that the interior walls of the conduit are smooth and free of burrs so that the wall of the plastic pipe is not damaged because of differential movement.

The installation of exposed plastic piping above ground is not recommended in areas where ambient temperatures are lower than 40°F or higher than 100°F. At the lower temperatures, the plastic materials are highly susceptible to brittle failure; at the higher temperatures, softening of the material causes deformation of the pipe and failure of joints. In addition, the plastic materials are more sensitive to impact loading than metal piping and must have positive protection against such damage. All of the three plastics considered here are either inherently resistant, or are provided with resistance through compounding additives, to damage from ultraviolet radiation from direct sunlight. However, direct solar radiation can raise the pipe wall temperatures substantially over ambient and should be avoided.

Thermal expansion of piping within a structure can be offset by a variety of design features, each dependent on the geometry and temperature fluctuations of the piping system. The simplest method takes advantage of the inherent flexibility of plastic piping by allowing unrestrained movement at points of directional change. In this manner, the axial stresses resulting from thermal expansion are translated into flexural (bending) stresses of a low order of magnitude as the movement is absorbed by the change in direction of the piping. This technique of offsetting thermal strain is normally adequate for one- and two-family residences with two stories or less. In larger buildings, relatively long runs of piping in both the horizontal and vertical direction may be involved. Restraint of the piping at the center of a run can help distribute the movement uniformly to both ends of a run where the smaller

movements can then be absorbed by directional changes.

When expansion cannot be accommodated by directional changes, or when piping is dimensionally constrained, because of other design conditions, to fixed terminal points, special provisions to accommodate movement may be required. Under such circumstances, several techniques can be employed, the most common of which is to provide offsets, lyre loops, or U-bends. For large-diameter pipe where lack of space might preclude the use of such bends, commercially available mechanical expansion joints can be used. These mechanical joints consist of a rubber O-ring inserted in a groove in the socket of the fitting and allow slippage of the pipe within to absorb linear movement. When mechanical expansion joints are used, the joint itself should be installed in such a manner as to prevent its movement; however, any intermediate support or fastener between mechanical expansion joints should be of loose fit to allow movement of the piping.

For internal piping installation, primary concern is with the means of supporting the pipe and the spacing of the supports. The external load carrying capabilities, and the amount of sag or deflection which occurs between supports of horizontal runs of piping in buildings at services temperatures, are a function of the support spacing. The weight per linear foot of thermoplastic piping, plus water conveyed, imposes only normal loads on individual hangers. But the relatively soft texture and low ring-strength of these materials requires that hangers with broad smooth bearing surfaces, rather than narrow or sharp edged contacts, be used to minimize stress concentrations, distortion, or physical damage to the pipe. Although clamp, saddle, friction or other standard types of hangers can be used, the strap type is preferable.

Unless dictated by specific design conditions, hangers should never be tightly clamped or attached to the piping in a manner that would prevent axial movement of the pipe due to thermal strain. It is sometimes desirable to rigidly clamp piping at valves to prevent continual twisting and pulling at the joint.

Pipe diameter, wall thickness and service conditions must be considered in the actual spacing and location of hangers; to provide sufficient rigidity to the system horizontal runs of piping should be supported at intervals of not less than 8 ft—near the end of branches, near changes in direction, and near ends of runs. Vertical piping should be supported at an interval of not less than every story and at its base.

Spacing of supports must limit sagging between supports (as a result of softening or creep at service temperatures under the weight of pipe plus conveyed water). Supports for piping of any diameter used within a building should be based on a maximum allowable sag between supports of 0.5 in. when water within the pipe is at normal maximum service temperature. This requires that spacing of hangers for cold water lines be based on exposure to water at 90°F. Table 15 lists recommended hanger spacing.

Individual hangers and supports should have a minimum bearing width of 0.75 in. Hanger straps should not be set so tight as to compress, distort, cut or abrade the piping. Plastic pipe hangers may be used to support pipe.

Inspection, Storage, and Testing. Material specifications for plastic piping and fittings contain quality control provisions covering the basic materials and the manufactured items. Certification that the specification requirements have been met should be obtained as part of any procurement action. Prior to installation of the pipe and fittings, however, certain inspections should be made to ensure that damage has not occurred during storage and shipment. A check should be made of piping and fitting dimensions. A visual inspection will permit identification of scratches, scars, cracks, wall deformation, plastic flow, and similar surface defects. For piping, the damaged area can be removed by cutting the section from the pipe. Damaged fittings should not be used in the piping system.

Plastic pipe without stabilizers has a limited outdoor life in direct sunlight due to the deterioration caused by the ultraviolet rays of the sun. Plastic pipe usually is manufactured with a stabilizer system that protects it from harmful radiation. If the pipe is to be used or stored above ground for extended periods, it should be stabilized with suitable additives such as carbon black. Non-stabilized (non-weather-resistant) pipe should not be used where exposure to weather is even a remote possibility. At ambient temperatures and protected from direct sunlight, plastic pipe has an indefinite storage life.

Plastic pipe may be stored either under cover or in the open, if it is suitably protected from aging due to sunlight. This is accomplished by the addition of the appropriate quantity and type of carbon black or other

Table 15
Recommended Support Spacings for Pipe Installations (in ft)

Pipe Size (in.)	Schedule 40 Maximum Service Temperature 20°F	60°F	80°F	100°F	120°F	140°F	160°F	Pipe Size (in.)	Schedule 80 Maximum Service Temperature 20°F	60°F	80°F	100°F	120°F	140°F	160°F
.5	5	4.5	4.5	4	2.5	2.5	2	.5	5.5	5	4.5	4.5	3	2.5	2.5
.75	5.5	5	4.5	4	2.5	2.5	2	.75	6	5.5	5	4.5	3	2.5	2.5
1	6	5.5	5	4.5	3	2.5	2	1	6.5	6	5.5	5	3.5	3	2.5
1.25	6	5.5	5.5	5	3	3	2.5	1.25	7	6	6	5.5	3.5	3	3
1.5	6.5	6	5.5	5	3.5	3	2.5	1.5	7	6.5	6	5.5	3.5	3.5	3
2	6.5	6	5.5	5	3.5	3	3	2	7.5	7	6.5	6	4	3.5	3
2.5	7.5	7	6.5	6	4	3.5	3	2.5	8.5	7.5	7.5	6.5	4.5	4	3.5
3	8	7	7	6	4	3.5	3.5	3	9	8	7.5	7	4.5	4	4
3.5	8	7.5	7	6.5	4	4	3.5	3.5	9.5	8.5	8	7.5	5	4.5	4
4	8.5	7.5	7	6.5	4.5	4	3.5	4	10	9	8.5	7.5	5	4.5	4
5	9	8	7.5	7	4.5	4	3.5	5	10.5	9.5	9	8	5.5	5	4.5
6	9.5	8.5	8	7.5	5	4.5	4	6	11	10	9.5	9	6	5	4.5

Note: (1) It is recommended that continuous support be used when individual support spacing becomes economically prohibitive.
(2) The above chart is based on Type I and Type II PVC pipe carrying liquids up to 1.35 specific gravity but does not include concentrated loads or other excessive stresses.
(3) If insulation is to be added, spans given above should be reduced at least 30%.

additive. Non-weather-resistant plastic pipe, however, must be stored under cover and protected from direct sunlight.

Coils may be stored either on edge or stacked flat, one on top of the other, but in either case they should not be allowed to come into contact with hot water or steam pipes, and should be kept away from all hot surfaces. Coils of large diameter (1 in. or more) should not be stored on edge in hot weather or direct sun.

Straight lengths should be stored on horizontal racks giving continuous support to prevent the pipe from taking on a permanent set.

Plastic pipe is made from a tough, resilient material which may be handled easily. However, because it is softer than metals it is more prone to damage by abrasion and by objects with a cutting edge; such practices as dragging coils over rough ground should be avoided.

Plastic pipe and fittings should not be allowed to come into contact with liquids that will impart taste or odor to the water for which the pipe is to be used. Ends should be plugged for storage.

Solvents and cements, if stored in sealed containers, also can be stored for periods of 2 to 3 years. Once the containers are opened, however, solvent evaporation is rapid. Such conditions can occur during fabrication. Solvents and cements which have been exposed to the air for longer than 8 hours should be discarded.

Piping systems must be tested after installation, but before coverage of buried installations. Testing procedures normally used for water piping systems are adequate. The piping systems should be thoroughly and completely tested for pressure strength and leakage before backfill operations are undertaken for underground systems. The line should be filled with water, with care taken to bleed all entrapped air in the process. The pressure should be slowly built up to 150 percent of maximum design pressure rating. The line should be inspected in its entirety while this pressure is maintained. Where leaks are discovered, they should be promptly repaired and the line re-tested. In some cases, it may be necessary to partially backfill the line before testing in order to hold the line in place. Where that is the case, the partial backfill should cover only the body of the pipe sections, leaving all joints and connections uncovered for inspection purposes. It should be demonstrated that the piping system will function properly at 150 percent of the maximum design pressure rating. At or below the maximum design pressure rating, there should not be (a) continuing unsteady delivery of water, (b) damage to the piping system, or (c) detrimental overflow from any control valves. Movement of the piping within the excavation should also be checked.

Table 16
Pipe Cost Comparison[18]

Pipe Size (in.)	Cost per Type of Pipe* Steel	Galvanized	Copper	Plastic (PVC or ABS)
1"	$0.40	$0.50	$1.20	$0.30
2"	0.85	1.00	3.15	0.50
4"	2.65	3.15	9.70	1.45
6"	5.35	6.50	19.85	2.95

* Cost per linear foot of pipe for material only—does not include handling and installation.
[18] Godfrey, R.S. Editor-in-Chief, *Building Construction Cost Data 1972,* Vol 30 (R.S. Means Co. Inc., 1972), p 238.

In addition to hydrostatic testing, piping installed within buildings should be inspected for deformation in the empty and pressurized states. Necessary freedom of movement within the support system and clearance from obstructions should be checked.

Piping System Costs. The economics offered by plastic pipe and fittings are evident in every phase of application, from original purchase to installed service. On an initial cost basis, the price of plastic pipe and fittings is less than that of other materials used for the same purpose. Table 16 illustrates the cost per type and size of material commonly used for water service.

While no definitive cost studies comparing plastic and metal pipe which included installation and maintenance costs were identified during this study, contact with users indicates savings can amount to approximately 30% with the use of plastic pipe in lieu of other materials. Construction cost estimating manuals indicate that material and installation costs for plastic pipe are significantly lower than for cast iron, copper, or steel pipes used in similar installation.

3 CONCLUSIONS AND RECOMMENDATIONS

Conclusions. Piping systems for potable cold water distribution systems in sizes up to 4 in. can successfully and economically utilize polyethylene, acrylonitrile-butadiene-styrene, and polyvinyl-chloride plastic piping and fittings when designed and installed in accordance with standards and practices established by national standard-setting groups and trade organizations.

Various means of fabricating pipe systems and joining elements have been established and are covered by recognized standards and practices. Fusion and welding methods are applicable only to factory fabrication.

Special attention must be given to the method of supporting plastic piping because of deformation or embrittlement at moderate temperature extremes and cold flow (creep) characteristics.

No means of evaluating the reasons for problems occuring with plastic piping exists outside the trade organizations and standards groups. The depth of investigation made of these problems is uncertain and the lag time in revising standards to reflect better materials and procedures is long.

Recommendations. If the standards and practices established by national and industry groups can be accepted for military use, plastic piping systems up to 4 in. diameter for cold, potable water should be used for military construction, except for outdoor, aboveground installations. A draft of necessary changes to Corps of Engineers Guide Specification CE-501, Water Lines, to cover the use of plastic piping is attached as Appendix I.

A detailed study of user experience should be made, both within DOD and in the civilian sector, to optimize methods of material selection and methods of fabrication and installation. Such a study should specifically cover, as a minimum:

1. Methods of joining and installing plastic piping.

2. Methods of supporting piping both underground and within buildings.

3. Skills and training required for making joints by the various methods and installing piping systems.

4. Inspection and sampling techniques necessary for ensuring quality and reliability under field conditions.

A study should be made of the applicability of plastic piping for hot water service within buildings.

APPENDIX I

RECOMMENDED ADDITIONS TO CORPS OF ENGINEERS GUIDE SPECIFICATION CE501 COLD WATER DISTRIBUTION

Additions to Existing Sections of CE501

2.1 (add)	L-P-00315b Pipe Plastic (polyethylene, PE SDR-PR) (12-7-67)
2.2 (add)	
D 1527-69	Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80
D 2468-69	Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Socket-Type, Schedule 40
D 2469-69	Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Socket-Type, Schedule 80
D 2282-69a	Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR and Class T)
D 2465-69	Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe Fittings, Threaded, Schedule 80
D 2672-68a	Bell-End Poly (Vinyl Chloride) (PVC) Pipe
D 2609-68	Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe
D 2104-68	Polyethylene (PE) Plastic Pipe, Schedule 40
D 2239-68	Polyethylene (PE) Plastic Pipe (SDR-PR)
D 2447-68	Polyethylene (PE) Plastic Pipe, Schedules 40 and 80 Based on Outside Diameter
D 2466-69	Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Socket-Type, Schedule 40
D 2467-69	Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Socket-Type, Schedule 80
D 1785-68	Poly (Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
D 2241-69	Poly (Vinyl Chloride) (PVC) Plastic Pipe (SDR-PR and Class T)
D 2464-68	Poly (Vinyl Chloride) (PVC) Plastic Pipe Fittings, Threaded, Schedule 80
D 2683-68T	Socket-Type Polyethylene Fittings for SDR 11.0 Polyethylene Pipe
D 2235-67	Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Pipe and Fittings
D 2564-67	Solvent Cements for Poly (Vinyl Chloride) (PVC) Plastic Pipe and Fittings
D 1180-57(1961)	Bursting Strength of Round Rigid Plastic Tubing (see Part 27)
D 2112-67	Dimensions of Thermoplastic Pipe and Fittings, Determining
D 2855-70	Making Solvent Cemented Joints with Poly (Vinyl Chloride) (PVC) Pipe and Fittings
D 2321-67	Underground Installation of Flexible Thermoplastic Sewer Pipe
D 2774-69T	Underground Installation of Thermoplastic Pressure Piping
D 2749-68	Plastic Pipe Fittings
2.6 (add)	National Sanitation Foundation (NSF) Standards NSF Standard No. 14, Thermoplastic Materials, Pipe Fittings, Valves, Traps, and Joining Materials.
3.1 (add)	...steel, Acrylonitrile-Butadiene-Styrene (ABS), Polyvinyl Chloride (PVC), or Polyethylene (PE), unless otherwise...
3.4 (add)	Plastic pipe certified for potable water service must bear the seal of the certifying organization.

New Sections for Addition to CE501

4.1.9 Polyethylene Plastic Pipe

(a) Pipe will be manufactured under Product Standards PS 10-69, 11-69, and 12-69 from extrusion materials conforming to ASTM 1248.

(b) Unstabilized (non-weather-resistant) pipe will not be used for application where even a remote possibility of exposure to sunlight exists.

(c) Pipe whose pressure rating (ASTM 2239 or 2247) equals or exceeds 125% of the maximum expected service pressure will be considered adequate for the installation.

(d) Pipe for potable water distribution will bear the seal of the certifying authority.

4.1.10 Polyvinyl Chloride Plastic Pipe

(a) Pipe will be manufactured under Product Standards PS 21-70 and 22-70 from extrusion materials conforming to ASTM 1755.

(b) Pipe whose pressure rating (ASTM 1785 or 2241) equals or exceeds 125% of the maximum expected service pressure will be considered adequate for the installation.

(c) Pipe for potable water distribution will bear the seal of the certifying organization.

4.1.11 Acrylonitrile-Butadiene-Styrene Plastic Pipe

(a) Pipe will be produced according to Product Standards PS 18-69 or PS 19-69 from resins conforming to ASTM 1788.

(b) Pipe, whose pressure rating (ASTM 1527 and 2282) equals or exceeds (125% of the expected service pressure will be considered suitable for the installation.

(c) Pipe for potable water distribution will bear the seal of the certifying organization.

4.2.10 Polyethylene Plastic Pipe

(a) Field joints and transitions will be accomplished using insert fittings meeting the specifications of ASTM 2609 and stainless steel clamps.

(b) Factory prefabricated pipe assemblies may contain joints made by butt fusion techniques.

(c) Insert fittings to be used in potable water service must bear the seal of approval of the organization having potability certification jurisdiction.

4.2.11 Polyvinyl Chloride Plastic Pipe

(a) Field joints will be accomplished by solvent cementing techniques using end-belled pipe or socket type couplings meeting the specifications of ASTM 2466 and 2467. Solvent cement will meet specification of ASTM 2564.

(b) Socket type couplings for potable water distribution must bear the seal of approval of the organization having potability certification jurisdiction.

(c) Schedule 80 and 120 PVC may be threaded and joined with threaded couplings meeting the standards of ASTM 2464.

4.2.12 Acrylonitrile-Butadiene-Styrene Plastic Pipe

(a) Field joints will be accomplished by solvent cement using socket couplings meeting specifications of ASTM 2468 and 2460. 80 ABS may be threaded and joined with threaded couplings meeting the standards of ASTM 2465.

(b) Couplings for use in potable water distribution systems must bear the seal of approval of the organization having potability certification jurisdiction.

4.3.8 For Polyethylene Plastic Pipe

(a) Insert fittings meeting the standard of ASTM 2609 will be used in conjunction with stainless steel hose clamps.

(b) Fittings for potable water use must bear the seal of approval of the organization having potability certification jurisdiction.

(c) Burst strength of the fittings must equal or exceed that of the pipe to which they are joined.

4.3.9 For Polyvinyl Chloride Plastic Pipe

(a) Socket fittings meeting the standards of ASTM 2466 and 2467 will be used.

(b) Threaded fittings meeting the standards of ASTM 2464 may be used in conjunction with Schedule 80 and 120 PVC pipe.

(c) Fittings for potable water use must bear the seal of approval of the organization having potability certification jurisdiction.

(d) Burst strength of the fittings must equal or exceed that of the pipe to which they are joined.

4.3.10 For Acrylonitrile-Butadiene-Styrene Plastic Pipe

(a) Socket fittings meeting the standards of ASTM 2468 and 2469 will be used.

(b) Threaded fittings meeting the standards of ASTM 2465 may be used for attachment to threaded ABS pipe.

(c) Fittings for potable water use must bear the seal of approval of the organization having potability certification jurisdiction.

(d) Burst strength of the fittings must equal or exceed that of the pipe to which they are joined.

4.10.8 Valves for Plastic Pipe Systems

(a) Metallic valves for plastic piping system must meet the appropriate specification listed within Section 4.5. Connection to the piping system will be made by appropriate threaded transition fittings. The transition fittings will have female pipe threads and the valve will have male pipe threads. Flanged valves may be used only in those instances where the torque on the bolts will be checked monthly as a part of routine maintenance. The value will be rigidly restrained to avoid transmission of torque to the pipe system.

(b) Plastic valves whose potability is certified by National Sanitation Foundation Standard No. 15 or equivalent standards and whose burst pressure exceeds that of the pipe to which it is attached may be used.

4.10.8 Solvent cements for joining ABS and PVC plastic pipe and fittings will conform to ASTM 2235 and 2564.

5.2.2 Plastic pipe may be cut using a carpenter's crosscut handsaw. Since square ends are an absolute necessity for proper joining, the assistance of a miterbox or similar device during cutting is desirable.

5.3.5 Plastic pipe shall be located a minimum of 12 inches below the maximum expected frost penetration depth.

5.5 Plastic pipe shall be installed in accordance with ASTM D2774 and manufacturer's recommendations where not in conflict with the ASTM.

5.6.11 Plastic pipe joints will be installed in accordance with sub-paragraph "Joints" under paragraph "Materials" as specific for the pipe material.

5.6.12 **Aboveground.** Exposed plastic piping shall not be installed above ground in areas where the minimum temperature is lower than 40°F or the maximum temperature is above 100°F. Piping shall be protected from physical damage and shielded from direct sunlight.

5.6.13 **Interior.** Piping shall be supproted by continuous tray or hangers. Hanger saddles have a minimum bearing width of 0.75 in. Hangers shall be spaced so as to limit midspan sag to not more than 0.75 in. when conveying water at 90°F, but in no case shall separation of hangers be greater than 8 ft. Vertical piping shall be supported, as a minimum, at every story and at the base. Piping shall not be required to carry the weight of pumps, valves, or vessels.

5.8.3 Plastic Pipe—no coating or wrapping required.

6.1.1 Plastic pipe will be tested at a minimum of 150% of rated pressure of as per applicable codes, whichever is greater. Pressure tests will be made on sections no longer than 5000 feet. Such testing will be initiated after expiration of the joint cure time according to the Table I-1 (ASTM 2855).

6.2.1 Leakage from plastic pipe joints is unacceptable. Leaking joints will be repaired, in the case of threaded, flanged, or insert fittings joints or replaced in the case of solvent cement joints. Such repair/replacement will be at no cost to the government. All pipe systems with repaired/replaced joints will be retested as per 6.1.1 and 6.2 above.

9.3 Storage. Piping shall be stored out of direct sunlight and shall not come into contact with heated surfaces. Straight lengths shall be stored on horizontal racks which provide continuous support. Coils may be stored flat or on edge. Fittings and solvent cements shall be stored in a cool, dry area. Solvents cements shall remain sealed until use.

Table I-1

	Test Pressures For Pipe Sizes 1/2 to 1 1/4 in.					
Temp Range During Cure Period, deg F	Up to 180 psi	Above 180 to 370 psi	Up to 180 psi	Above 180 to 315 psi	Up to 180 psi	Above 180 to 315 psi
60 to 100	1 h	6 h	2 h	12 h	6 h	24 h
40 to 60	2 h	12 h	4 h	24 h	12 h	48 h
10 to 40	8 h	48 h	16 h	96 h	48 h	8 days

Note: These cure schedules are based on laboratory test data obtained on Net Fit Joints (NET FIT = in a dry fit the pipe bottoms snugly in the fitting socket without meeting interference). The relative humidity in these tests was 50 percent or less. Higher relative humidity may require longer cure periods.

GLOSSARY

Acrylonitrile-Butadiene-Styrene (ABS) Pipe and Fitting Plastics: Plastics containing polymers and/or blends of polymers, in which the minimum butadiene content is 6 percent, the minimum acrylonitrile content is 15 percent, the minimum styrene and/or substituted content is 15 percent, and the maximum content of all other monomers is not more than 5 percent, and lubricants, stabilizers, and colorants.

Allowable Working Stress: The maximum hoop stress permitted by code for the design of a piping system.

Cold Flow: The dimensional change with time of a plastic under load, following the instantaneous elastic or rapid deformation. (Also referred to as 'creep'.)

Compressive Strength: The crushing load at failure per unit area of minimum original cross section carried by a specimen.

Design Pressure: The maximum operating pressure permitted by the USASI B31.8 code, as determined by the design procedures applicable to the material and location involved.

Elastomer: A material which at room temperature can be stretched repeatedly to at least twice its original length and upon immediate release of the stress, will return with force to its approximate original length.

Epoxy Resins: Resins made by the reaction of epoxides or oxiranes with other materials such as amines, alchols, phenols, carboxylic acids, acid anhydrides, and unsaturated compounds.

Extrusion: A method whereby heated or unheated plastic forced through a shaping orifice becomes one continuously formed piece.

Filler: A relatively inert material added to a plastic to modify its strength, permanence, working properties, or other qualities, or to lower costs.

Fuse: To join two plastic parts by softening the material with heat.

High-Density Polyethylene: Type III polyethylene with a density of 0.941 to 0.965 g/cc.

Hoop Stress: The stress imposed in the wall of a cylindrical tube in the circumferential direction by internal pressure.

Hydrostatic Design Stress: The estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with a high degree of certainty that failure of the pipe will not occur.

Impact Strength: Force required to break a specimen by a sudden blow.

Injecting Molding: The process wherein a plastic is heat softened to a flowable state and forced into a cooler mold or die to the desired shape. Fittings are usually made by this process.

Long-Term Hydrostatic Strength: The estimated tensile stress in the wall of the pipe in the circumferential orientation that when applied continuously will cause failure of the pipe at 100,000 hours.

Maximum Allowable Operating Pressure: The highest pressure that a gas distribution system can be operated under the USASI Code for Pressure Piping.

Methyl Ethyl Ketone (MEK): An organic solvent widely used for preparing solvent cements, formula $C_2H_5COCH_3$.

Permanent Set: Any deformation in a piece of plastic (or metal) which remains after the removal of the stress which caused the deformation.

Plastic Pipe: A hollow cylinder of a plastic material in which the wall thicknesses are usually small when compared to the diameter and in which the inside and outside walls are essentially concentric. Usually made from rigid or semirigid plastics.

Plastic Tubing: Same as plastic pipe except it is usually made from nonrigid plastics or is of small diameter.

Plasticizer: A material incorporated in a plastic to increase its workability and its flexibility or distensibility.

Polyethylene: A plastic or resin prepared by the polymerization of ethylene as essentially the sole monomer.

Polymer: A compound formed by the reaction of simple molecules having functional groups that permit their combination to proceed to high molecular weights under suitable conditions. Polymers may be formed by polymerization (addition polymer) or polycondensation (condensation polymer). When two or more monomers are involved, the product is called a copolymer.

Polymerization: A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more different monomers are involved, the process is called copolymerization.

Polypropylene: A plastic or resin prepared by the polymerization of propylene as essentially the sole monomer.

Polyvinyl Chloride (PVC): A resin prepared by the polymerization of vinyl chloride alone.

Quick Burst: A test to determine the pressure required to burst a pipe when applied in a short period of time (in order of 60–90 seconds). Use as a rapid check on quality control.

Reinforced Plastic: A plastic with some strength properties greatly superior to those of the base resin, resulting from the presence of high-strength fillers imbedded in the composition.

Resin: A solid, semisolid, or pseudosolid organic material which has an indefinite and usually high molecular weight, exhibits a tendency to flow under stress, and usually has a softening or melting range. The plastic material before forming by extrusion or molding.

Solvent Cementing: Joining pipe by the use of a solvent or cement which dissolves the surface of the pipe and forms a continuous bond upon evaporation.

Stabilizer: An ingredient used in the formulation of some plastics to assist in maintaining the physical and chemical properties of the compounded materials at their initial values throughout the processing and service life of the material.

Styrene-Rubber (SR) Pipe and Fitting Plastics: Plastics containing at least 50 percent styrene plastics combined with rubbers and other compounding materials, but less than 15 percent acrylonitrile.

Tensile Strength: The tensile stress necessary to cause failure in a short-time test. Performed by pulling a specimen of specified dimension at a specified rate.

Thermoplastic (noun): A plastic which is thermoplastic in behavior.

Thermoplastic (adjective): Capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature.

Thermoset: A plastic which, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble product.

Yield Point: The stress at which a material exceeds its elastic limit. Below this stress the material will recover its original size on removal of the stress. Above this stress, it will not.

ABBREVIATIONS

ABS	Acrylonitrile-Butadiene-Styrene
ASTM	American Society for Testing and Materials
CAB	Cellulose Acetate Butyrate
CS	Commercial Standard
DWV	Drain Waste and Vent
ESC	Environmental Stress Cracking
FHA	Federal Housing Administration
MEK	Methyl Ethyl Ketone
NSF	National Sanitation Foundation
PE	Polyethylene
PPI	Plastic Pipe Institute
PVC	Polyvinyl Chloride
PVDC	Polyvinyl Dichloride
RTRP	Reinforced Thermosetting Resin Pipe
SPE	Society of Plastics Engineers
SPI	Society of Plastics Industry, Inc.
USASI	United States of America Standards Institute

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13. ABSTRACT

This report evaluates the suitability of unreinforced plastic piping for use in small diameter (less than or equal to 4 in.), interior and exterior potable cold water distribution systems. Special consideration was directed toward the storage, handling, fabrication and installation techniques peculiar to plastic pipe. Also included are guidelines for the design and installation of plastic piping systems. Three major resins were considered: acrylonitrile-butadiene-styrene (ABS), polyvinyl-chloride (PVS) and polyethylene (PE). Polyethylene pipe is suitable only for low pressure applications; PVC and ABS pipe meet the study criteria of being able to withstand a pressure of 150 $lb/in.^2$ An appendix recommends additions to Corps of Engineers Guide Specification CE 501, Cold Water Distribution.

14. KEY WORDS

cold water distribution   plastic pipe   plastic piping systems

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PLASTIC PIPE FOR INTERIOR AND EXTERIOR COLD WATER DISTRIBUTION SYSTEMS

Technical Report E-14, May 1973, 28 pp, by Walter J. Mikucki

This report evaluates the suitability of unreinforced plastic piping for use in small diameter (less than or equal to 4 in.), interior and exterior potable cold water distribution systems. Special consideration was directed toward the storage, handling, fabrication and installation techniques peculiar to plastic pipe. Also included are guidelines for the design and installation of plastic piping systems. Three major resins were considered: acrylonitrile-butadiene-styrene (ABS), polyvinyl-chloride (PVS) and polyethylene (PE). Polyethylene pipe is suitable only for low pressure applications; PVC and ABS pipe meet the study criteria of being able to withstand a pressure of 150 lb/in.^{2} An appendix recommends additions to Corps of Engineers Guide Specification CE 501, Cold Water Distribution.

KEY WORDS

cold water distribution
plastic pipe
plastic piping systems

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